Map readers' assessment of path elements and context to identify movement behaviour in visualisations

Lautenschütz, Anna-Katharina

Abstract: Understanding the complex nature of movement data and integrating it sufficiently into visual analytics tools is largely missing in GIScience. A user experiment assesses quantitatively and qualitatively which path elements contribute to map readers' ability to identify a moving object and its behaviour in visual displays of movement. Context was added as a control variable by showing the movement path either on a homogenous background or embedded in a terrain map. The analysis shows that participants mainly used the character of the line and the shape of the represented behaviour to interpret the visualisation. Independently of context information, participants use the same path elements. With this approach, we hope to provide a first stepping-stone to identify the key elements that contribute to map readers' ability to understand and analyse movement behaviour with visual analytics tools.

DOI: https://doi.org/10.1179/1743277412Y.0000000029

The Cartographic Journal Vol. 49 No. 4 pp. 337–349 Cognition, Behaviour, Representation - Special Issue November 2012

REFEREED PAPER

Map Readers' Assessment of Path Elements and Context to Identify Movement Behaviour in Visualisations

Anna-Katharina Lautenschütz

Department of Geography, University of Zürich, Winterthurerstr. 190, 8057 Zürich, Switzerland
E-mail: a-k.lautenschuetz@geo.uzh.ch

Understanding the complex nature of movement data and integrating it sufficiently into visual analytics tools is largely missing in GIScience. A user experiment assesses quantitatively and qualitatively which path elements contribute to map readers' ability to identify a moving object and its behaviour in visual displays of movement. Context was added as a control variable by showing the movement path either on a homogenous background or embedded in a terrain map. The analysis shows that participants mainly used the character of the line and the shape of the represented behaviour to interpret the visualisation. Independently of context information, participants use the same path elements. With this approach, we hope to provide a first stepping-stone to identify the key elements that contribute to map readers' ability to understand and analyse movement behaviour with visual analytics tools.

Keywords: movement visualisation, experiment, map reading, path elements

INTRODUCTION

Animals and humans move on the earth's surface, to find food, places of shelter, and to communicate with one another. Movement of point objects, like animals and humans, has been a focus of interest in geography and cognate research areas for many decades (Dykes and Mountain, 2003; Gianotti and Pedreschi, 2008; Gudmundsson *et al.*, 2012). With advances in technology, movement data can be captured more easily than ever. Humans use mobile phones, digital navigation devices or GPS to get location information. The availability of large amounts of movement data facilitates the development of various analysis methods to analyse movement data, not only in terms of what and where movement has happened, but also to get insights into why movement has happened. The exploration of moving point datasets for identifying movement patterns has led to a variety of approaches (Buchin *et al.*, 2009; Dodge *et al.*, 2009; Gudmundsson *et al.*, 2004; Laube *et al.*, 2005) as well as tools, such as Hawths Tools, Home Range extension and Tracking Analyst for ESRI's ArcMap. Common to these approaches and tools is that movement data are analysed with algorithms according to basic movement parameters, such as speed, distance, direction and velocity (Dodge *et al.*, 2008). A remaining question is whether humans use these same basic movement parameters in a visual analysis to understand movement behaviour.

From a visualisation perspective, only limited research has been carried out to integrate spatio-temporal data at the human interface level. The display influences how well the analyst can solve visual analysis tasks, i.e. a well-designed interface/display helps the analyst to better understand and analyse spatio-temporal data. It is specifically important to comprehend humans' knowledge construction and reasoning about spatial and temporal phenomena and processes in order to improve their capacity to visually extract movement patterns and make informed decisions when analysing the data, and to ultimately develop empirically validated guidelines for the construction of cognitively inspired visualisations of movement.

The analysis task determines what the analyst is trying to find out, e.g. looking for home ranges or the identification of similarities between movement trajectories. Understanding if humans are able to identify movement behaviour with visual displays is the key question of this user experiment. This could potentially lead to the design of perceptually salient displays where the most important path elements from a cognitive point of view are also highlighted visually.

Another factor to make the data more accessible for users is the integration of context information, specifically the geographic environment in which movement takes place, e.g. alpine terrain for an ibex. Although researchers argue for the inclusion of context information, so far, only a few approaches explicitly integrate context or semantic information in the analysis of movement data with the goal to identify movement patterns (Yan *et al.*, 2008; Schmid *et al.*, 2009). However, this approach might be indispensable to detecting behavioural movement patterns in animal or human behaviour, such as foraging, or flight and pursuit.

DOI: 10.1179/1743277412Y.0000000029

In this paper, we describe a user experiment that tries to assess which path elements are contributing to a map reader's ability to identify moving objects and their behaviour. The experiment uses geographic context as a control variable to assess to what extent context information influences the path elements chosen for interpreting a representation of movement. The next section embeds the experiment briefly into the current state of the art for spatio-temporal reasoning, and different approaches to visualize spatio-temporal data.

BACKGROUND

Dynamic geographic processes, such as movement, have not only gained increasing attention in GIScience, but also in cartography and visualisation (Yattaw, 1999). In order to understand how humans understand spatio-temporal data and why certain visualizations work better than others, we have to understand how our mind reasons about space and time. One potential theoretical construct to study movement behaviour from a cognitive perspective is image schemata. Image schemata rely on a small set of experiential concepts and are cognitive structures that help us make sense of our perceptions and actions (Lakoff and Johnson, 1980). The source–path–goal schema described by Lakoff (1987) is particularly useful for understanding spatio-temporal data, especially movement data, as its structural elements are a starting point (source), an endpoint (goal), and a sequence of locations connecting the source and the destination (path) (Lakoff, 1987). Movements are commonly represented as space–time paths in visualisations (Hägerstrand, 1970); space–time paths have a start point, an end point and change points in-between. These change points, or occurrences, can also be called events. Within GIScience, we find a variety of definitions for processes and events (Worboys, 2005; Galton, 2009), in which events are seen as part of a process and processes are made up of events. We use Worboys's (2005) definition of events for all kinds of occurrences, e.g. the change of direction in a movement path.

Events from a cognitive perspective are mental units and are considered to be building blocks in the temporal realm (Schwan and Garsoffky, 2008; Shipley, 2008). Although events are seen as units, analogies can be drawn between events and objects (Casati and Varzi, 2008; Schwartz, 2008; Shipley, 2008; Shipley and Maguire, 2008). While objects belong to the spatial dimension without a temporal frame of reference, events are set in the temporal dimension (Casati and Varzi, 2008; Shipley, 2008; Tversky *et al.*, 2008) and occur when objects change or interact (Shipley, 2008). Experiments with the goal of identifying potential perceptual features of event boundaries have focused on the motion of individual objects in space (Shipley and Maguire, 2008; Tversky *et al.*, 2008; Zacks, 2004). Although events and objects are clearly different, the possibility of drawing analogies between events and objects leads to the potential to model and analyse events with GISystems.

Event-based approaches are becoming more popular in geovisualisation, as they actively integrate cognitive principles into visual displays (Yattaw, 1999; Worboys and Hornsby, 2004; Kapler and Wright, 2005; Worboys, 2005; Beard, 2006; Beard *et al.*, 2007; Hornsby Stewart and Cole, 2007; Aigner *et al.*, 2008; Yuan and Stewart Hornsby, 2008). These approaches are promising, because they not only provide user interactivity, but also combine it with humans' conceptualisations of spatio-temporal processes as successive events. Following Yattaw (1999), the event-based approach seems useful, because it also allows the user to understand the individual spatial and temporal components of each event separately, a pre-requisite to understanding processes and relationships between movement patterns.

The most basic conceptualisation of a moving object's space–time behaviour is a geo-spatial lifeline (Hornsby and Egenhofer, 2002) – also referred to as a movement path or trajectory, which describes a sequence of visited locations in space, at regular or irregular temporal intervals (Laube *et al.*, 2005). In this paper, we use the term 'movement path' as a synonym for movement trajectory. Current state-of-the-art movement pattern research focuses mostly on the automated analysis of geometric properties and features of paths, and the extraction of movement patterns by means of algorithms (Laube *et al.*, 2007; Dodge *et al.*, 2009; Mennis and Guo, 2009). However, we do not know whether the geometric properties extracted by algorithms match humans' internal representations, i.e. which geometric features in a visual analysis adequately capture the semantics of the movement behaviour.

Researchers argue that a better understanding of perceptual-cognitive tasks in the context of visualisation has to be attained and supported by empirical evidence (MacEachren and Kraak, 2001; Chen, 2005; Fuhrmann *et al.*, 2005). Existing iterative design-processes involve the users early on in the design and implementation of visualisations as the users are then able to apply visualisation techniques and concepts to understand and analyse their data on a more informed level (Robinson *et al.*, 2005; Koh *et al.*, 2011; Lloyd and Dykes, 2011). Certainly, good starting points for constructing effective and efficient visual analytics displays are the design principles for how to transform spatio-temporal data into visuo-spatial forms, outlined in various standard cartography textbooks (e.g. Slocum, 2008). Bertin's (1983) system of visual variables, and later extensions into the dynamic domain by DiBiase *et al.* (1992), are also prime candidates for movement visualisations. In cognitively inspired visualisations, thematically relevant information should be rendered perceptually most salient for effective and efficient spatio-temporal inference and decision-making (Fabrikant *et al.*, 2010). Visualisations of movement data should therefore carefully consider which geometric properties (i.e. shape, start- and end-points, etc.) should be visually highlighted to enhance map readers' ability to identify moving objects and their behaviour.

Other major factors required for an adequate depiction of movement include context information, i.e. the surrounding environment of the moving object, researchers' goals and analysis tasks, as well as the spatio-temporal scale at which the data are captured. From a behavioural ecology perspective, geographic location seems to be a very important context element for understanding movement and its behaviour. For instance, Nathan *et al.* (2008) note that the geographic context is a key element for

Figure 1. Geographic context is manipulated by a homogeneous background (left) or a terrain map (right)

understanding which external factors affect animal movement. Recent developments from a computational perspective also include context, for instance, when assessing similarity of movement trajectories (Buchin *et al.*, 2012). In this experiment, we therefore use geographic context as a control variable to assess to what extent context information influences the path elements chosen for interpreting a representation of movement. The main goal of this experiment is to assess which path elements contribute to map readers' ability to identify movement behaviour in visualisations of movement. This experiment is a first attempt to improve our understanding of humans' reasoning with spatio-temporal data. The next section explains the design of the experiment.

EXPERIMENTAL DESIGN

Participants

In total, 46 participants completed the online experiment. Two participants were eliminated from the analysis. One participant did the online questionnaire on a smart phone, i.e. with a screen size of approximately nine inches, which was considered too small to visually examine the representation of a movement path in detail. The second participant suffers from a red-green colour vision deficiency, which significantly limits the visibility of a red line on the terrain map. Subsequently, data from 44 participants was analysed in this experiment: 57% of the participants were male and 43% were female. Sixty-eight per cent of participants were between 20 and 30 years, an effect of sending the invitation to students and colleagues. Sixteen per cent were between 31 and 40 years, 14% were between 41 and 60 years and only 2% of participants were older than 60 years.

Experimental design

Human movement data collected for the Mafreina research project (http://www.mafreina.ch) from the University of Applied Sciences in Wädenswil, Switzerland, were used to construct movement trajectories. The data consists of GPS tracks that were recorded during various outdoor activities in the Swiss National Park. Participants studied movement paths represented by a temporal sequence of GPS fixes, i.e. dots, on a 17-inch sized display. The stimuli were generated by overlaying the GPS tracks on Google Maps. The experiment is set up as a two (behavioural context) by two (geographic context) by two (orientation) factorial design. Context is introduced as the independent variable. The experiment is a within-subjects design, with geographic context being the within-subjects factor, i.e. participants were presented with both geographic context conditions throughout the experiment (see Figure 1 for examples of geographic context).

Behavioural context includes two conditions based upon (goal directed) outdoor activities: skiing on slopes (later referred to as 'piste') and backcountry skiing (later referred to as 'tour'). These two conditions create distinctly different movement patterns (as shown in Figure 2). Downhill skiers move (rapidly) downhill within a well-defined elongated area of groomed slopes, always in the vicinity of existing ski lift infrastructure (slower and mostly straight uphill movement). Backcountry skiers, on the other hand, hike (slowly) uphill on (sometimes) meandering tracks and ski more rapidly downhill, unrestricted by human-made infrastructure.

To create the two orientation conditions, one-half of the trajectories were the original GPS tracks, while the others were rotated horizontally by 180°. The rotated trajectories are therefore, when presented with geographic context information, not in their true geographic location, and thus not in a spatially meaningful environment.

The questions and the stimuli were presented through a web questionnaire. The assignment of participants to the groups was randomized using a *.php script. In total, each group had to answer 16 questions for four stimuli without geographic context information and 16 questions for four stimuli with geographic context information. Participants were first presented with the displays without any context information to avoid potential learning effects from seeing the representation of a movement path on a terrain map.

The experiment was piloted in two phases with a total of five students at the Geography Department of the University of Zurich. The first pilot round with two participants suggested that a within-subjects design was preferable to a between-subjects design (i.e. where participants are presented with only one context condition throughout the experiment), because it allows us to see changes in participants' behaviour more directly.

Procedure

The questionnaire was sent as an online invitation to approximately 100 undergraduate students of the

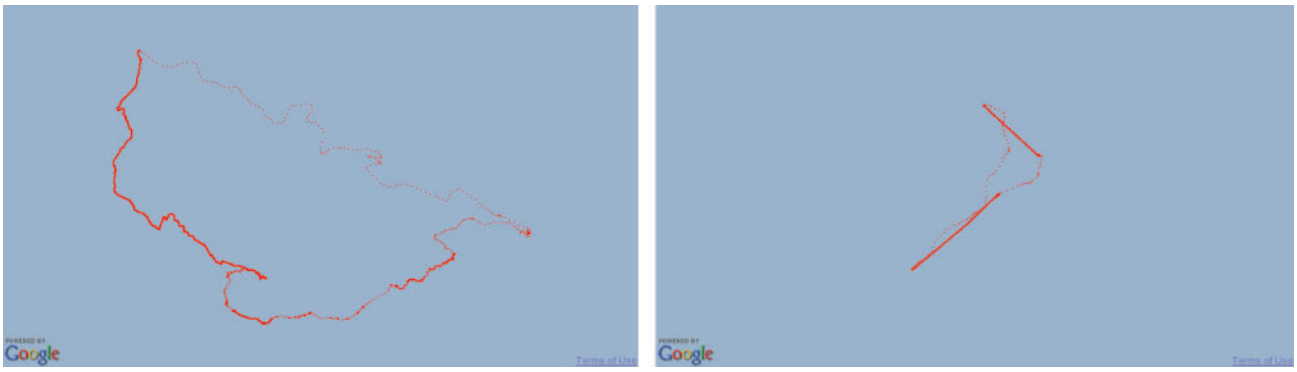

Figure 2. Behavioural context is differentiated by two activities: ski touring (left) and skiing on slopes (right)

Department of Geography, as well as to about 100 friends and colleagues. Participants were not required to have a geography background. After getting an introduction to the experiment on a website, participants were randomly forwarded to one of the four questionnaires.

Each participant answered two qualitative (i.e. open text) questions and two quantitative questions. The dependent variables are confidence and accuracy (from the second and third questions). The four experiment questions were:

1. What do you think is presented here in red? You can name anything that you consider to be correct.
2. How confident do you feel about your answer?
3. Who or what do you think has moved?
4. What else comes to your mind?

The open questions ('what do you think is presented here in red?' and 'what else comes to your mind?') were intended to get insight into whether participants initially identified the movement representation either as an object or as a representation of a process, and which path elements participants used for their reasoning. Participants answered the first question by writing their impressions into an open text field. In the second question, participants rated their confidence on a Likert scale ranging from one, indicating 'very unsure', to five, indicating 'very confident'. The third question asked participants to identify the moving object. Participants could choose from one of four options, namely, animal, human, natural phenomenon or machine. In the fourth question, participants could state any additional comments and impressions in an open text field. After four different stimuli without geographic context information, participants saw the same stimuli with geographic context information and answered the respective questions. Finally, participants answered some demographic questions, such as those about their age, gender, their familiarity with GPS data, the screen size they used, their hobbies, and whether they have any red-green/colour vision deficiencies. The experiment took approximately 20 minutes and was conducted completely anonymously.

RESULTS

For the analysis of the qualitative data, i.e. the open questions, we inspected the data to identify possible response categories. Obviously, categories are different for the different behavioural contexts, as the representations of the two activities generated two distinctively different spatial patterns. However, some potential categories are applicable to both activities, like the movement path of a human, or the movement path of an animal. The categories identified for the first question (Q1) are:

> *Movement path animal, movement path human, trail, border, river, region, ski area, natural phenomenon, cable car, combination of technical and trail, technical installation, air traffic, other, and no idea.*

We then aggregated these categories into two classes: object-oriented concepts and process-oriented concepts. Object-oriented concepts included three sub-classes: technical objects (cable car, technical installation, combination of technical and trail), line objects (trail, border, river) and polygons (region, ski area). Process-oriented concepts included all categories where participants indicated a movement, i.e. a series of changes or actions that lead to a certain spatial pattern, such as hiking to a mountain.

The categories identified for the second question (Q4) are:

> *Speed, direction, shape, character of line, start and end point, clear interpretation ideas, unclear interpretation, and topography.*

All answers from participants were classified according to these categories and are reported in the following section.

Explanation of the path

When asked what the red path represents, aggregated across behavioural contexts, the majority of participants described the 'tour' condition as an object-oriented concept, such as a trail, border or region (Figure 3). The majority of participants, on the other hand, described the 'piste' condition as a process. However, their judgements changed when geographic context was introduced. While participants thought the 'tour' condition was an object-oriented concept without geographic context and a process-oriented concept with geographic context information, participants were more likely to choose a process-oriented concept for the 'piste' condition when no geographic context was provided than when it was provided.

When looking at the object-oriented sub-classes (Figure 4), we can see that line objects were mentioned more often in the 'tour' condition than the 'piste' condition, while participants

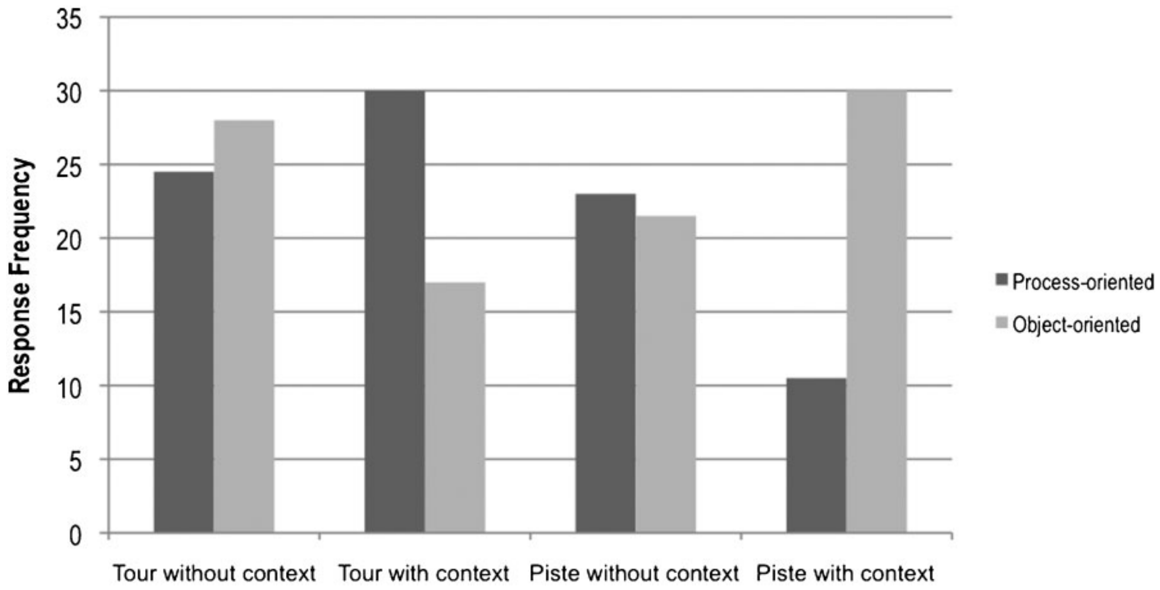

Figure 3. Response frequency for process-oriented or object-oriented concepts by behavioural context

typically described the 'piste' condition as a technical object. This corresponds to our findings from Question 4, in which participants repeatedly referred to path elements when interpreting the path. The fourth question, where participants could add information, was a very valuable open text field, as participants often used it to add their personal interpretation, or explain the reasoning behind their answer to the first question.

Figure 5 shows that the response frequency of path elements used is substantially different for the different behaviours. Most participants mentioned that they used the character of the line (i.e. dots or solid line) to interpret the movement path when looking at representations of the 'tour' behaviour. For the 'piste' behaviour, participants mainly focused on the shape of the line with its straight and bent lines. Participants indicated that straight lines seem to be man-made or of a technical nature, which corresponds nicely to the object-oriented concept described earlier. When no context was available, participants gave more unsure interpretations of what they were looking at (Figure 6). 'Unsure interpretations' include all interpretations that were incorrect or where participants indicated that they felt unsure. The addition of context almost halved the number of unsure interpretations (69% of interpretations versus 33% in the Tour behaviour; 78% versus 44% in the Piste behaviour). When context was provided, not only did participants focus less on path elements (Figure 5), they also provided clearer and more precise interpretations of the movement path. Topography was almost exclusively mentioned when the path was presented with context information. Further analysis revealed that notions of

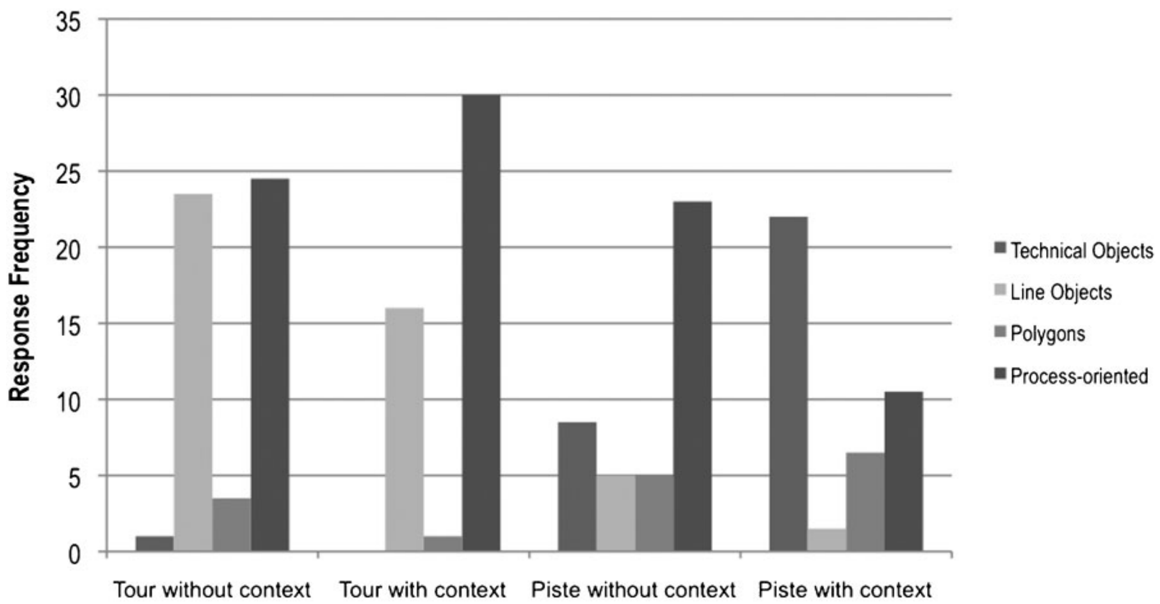

Figure 4. Response frequency for object- and process-oriented categories

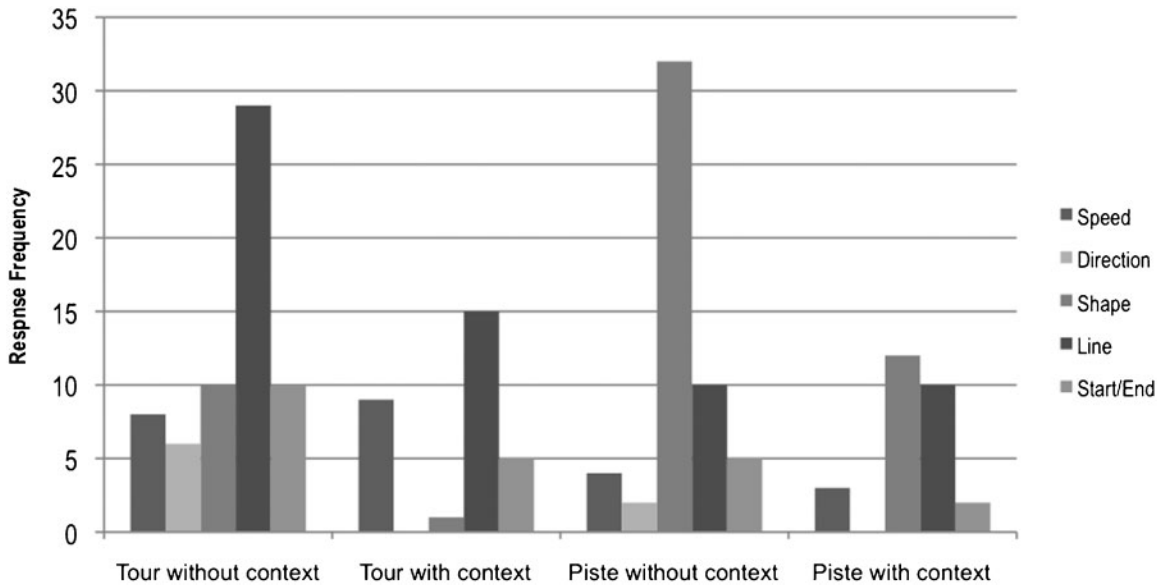

Figure 5. Response frequency of path elements used to describe the red element in the visualisation (Q4)

topography were used almost exclusively when the path was placed incorrectly in the environment.

Process-oriented reasoning

We now examine the response frequencies among only those participants who immediately interpreted the representation as a movement, i.e. participants who employed a process-oriented concept. We only examine the first question asked for each behaviour, for both with and without geographic context information. The assumption is that participants are totally unbiased when answering these questions, because they have not seen another representation of this behaviour at an earlier stage.

Without geographic context information, participants believe that the representation is the movement path of an animal or a human, giving a variety of answers, e.g. a hunting lion, an ant searching for food or someone biking. When looking at the response frequencies with geographic context information, participants assumed that the red representation was a human movement path (Figure 7).

Figure 8 shows again that most participants used the shape of the representation with its straight and bent lines for describing the 'piste' behaviour and dispersion of points along the line to interpret the representation of the 'tour' behaviour. This corresponds to the fact that fewer participants chose a process-oriented concept for their explanation in the piste behaviour. The start and end points of the representation are hardly ever mentioned. Speed was, in the majority of cases, mentioned together with the dispersion of points along the

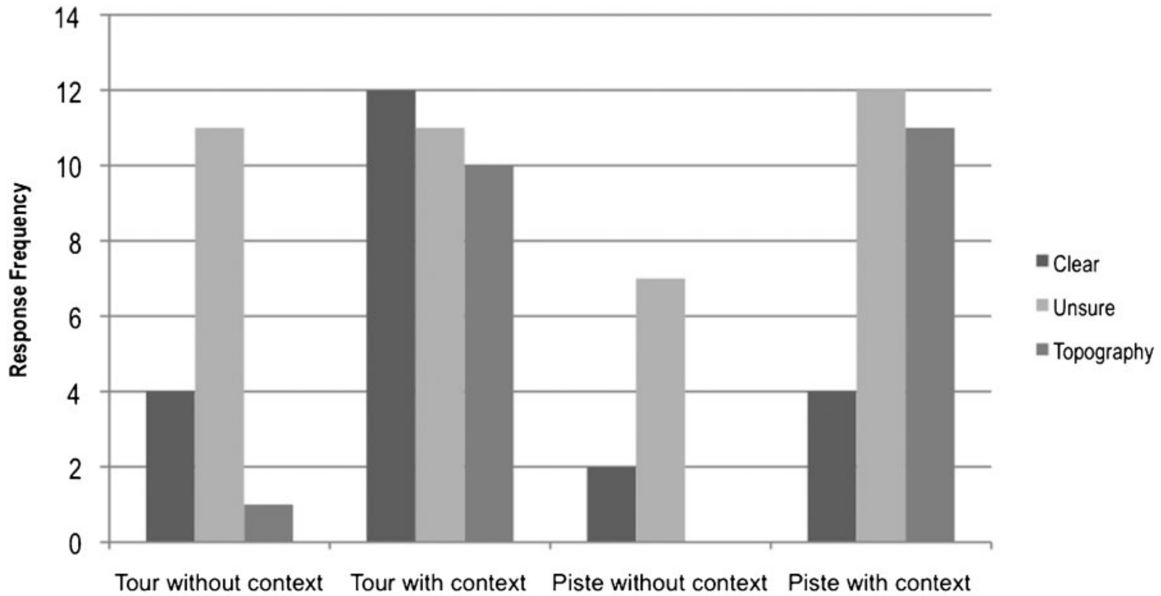

Figure 6. Q4 interpretation response frequency for all participants

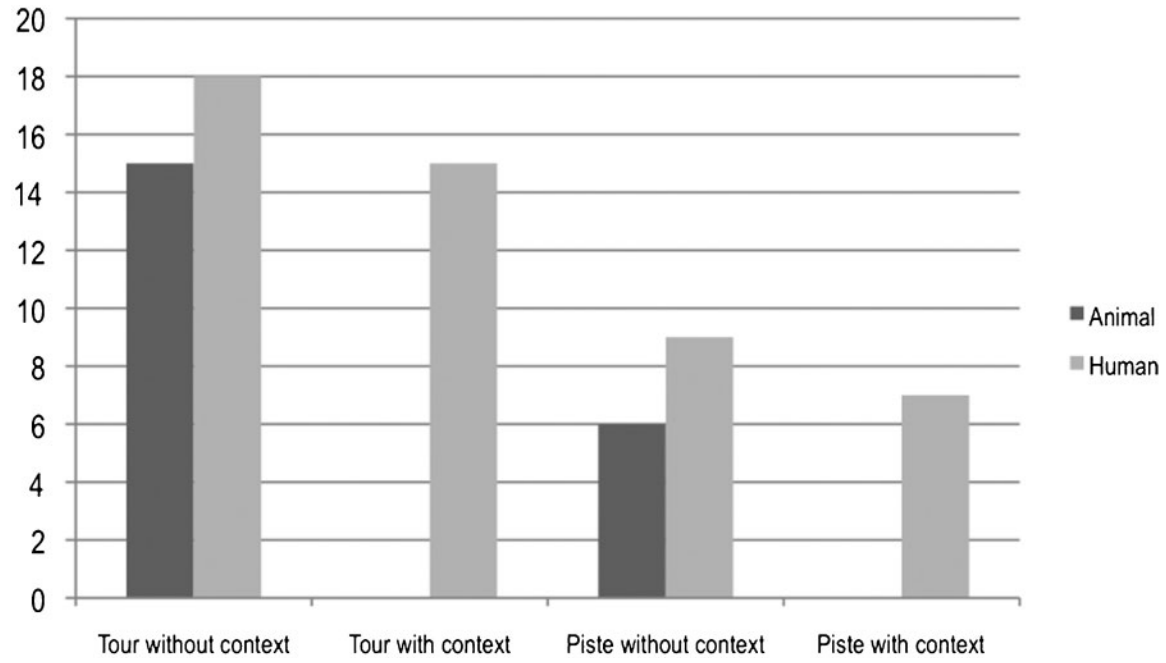

Figure 7. Type of trajectory (human or animal) response frequency for process-oriented categories only

line, usually interpreting the correlation correctly that dots that are further apart indicate higher speed.

As seen earlier, participants interpreted the representation of the movement path correctly more often when context information is provided. Without context information, interpretations are usually unsure (as indicated by the participants) and incorrect (Figure 9).

We can briefly summarize the qualitative analysis by stating that participants mainly refer to the dispersion of points along the line and the shape of the representation for their interpretation.

Confidence

In a second step, we analysed participants' confidence in order to understand how comfortable they are with their interpretations and to what extent context influenced their confidence. On average, participants' confidence rating was 2.87 on a scale from 1 to 5, with a mean confidence of 2.33 without any context information, and a mean confidence of 3.38 when context information was available. In other words, participants feel more confident when geographic context information is available, because it allows participants to see where the movement has happened.

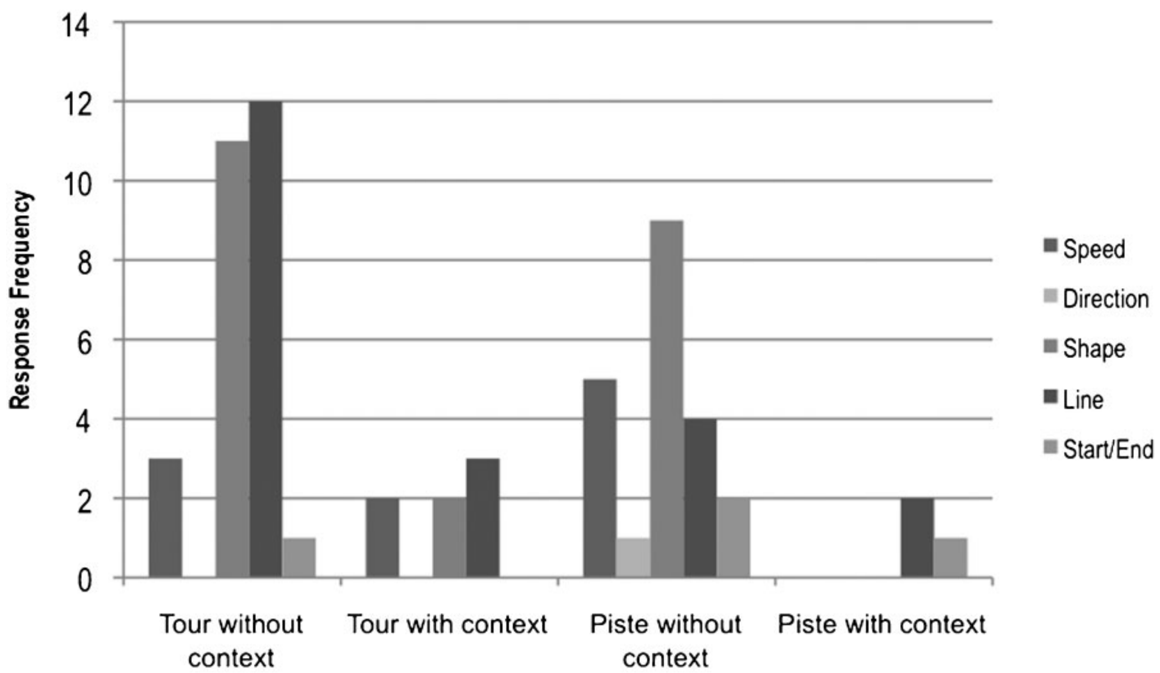

Figure 8. Response frequency of path elements used to interpret the red element for the first sighting of the red element

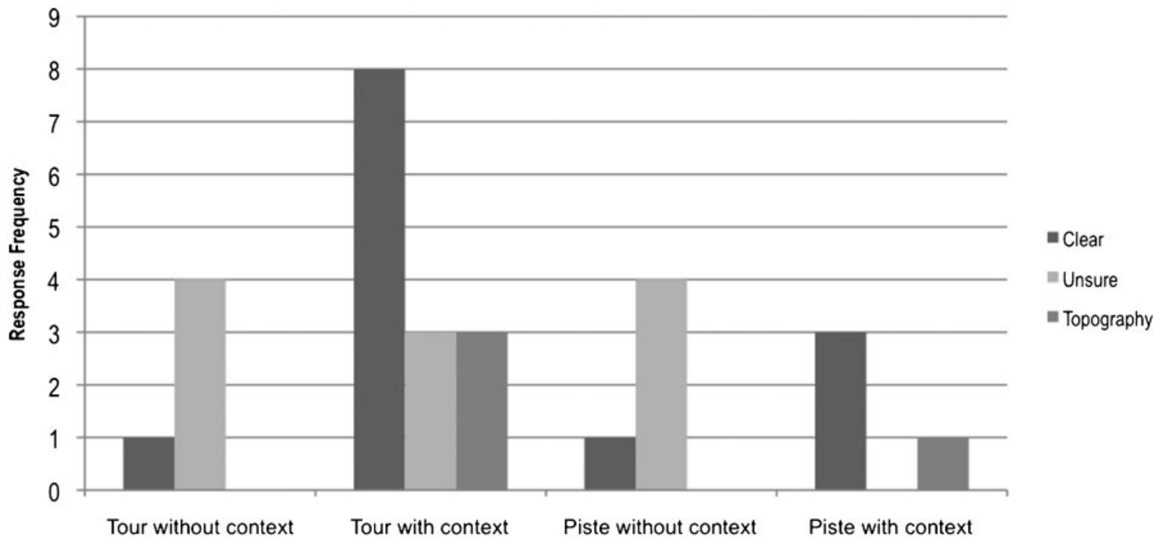

Figure 9. Interpretation response frequency for process-oriented categories only for the first sighting of the red element

Specifically, we explored the data according to whether the geographic context was correctly oriented (as described earlier), i.e. whether the movement path is situated in its true geographic location. Figure 10 shows one movement path, in its correct geographic location (in figures referred to as 'true'; Figure 10a) and an incorrect geographic location (in figures referred to as 'false'; Figure 10b). A meaningful movement path leads onto Piz Tarretas and back for the behaviour 'tour' (Figure 10a), while in Figure 10b, the movement path crosses steep cliffs and does not have a meaningful start and end point.

When participants are presented with trajectories that show their true location spatially meaningful participants are more confident in their responses than when compared to the condition where the movement path is not shown in its correct geographic location (Figure 11). This corresponds to our earlier findings that participants describe the representation as unclear (as seen in Figure 9) when it is not placed in a spatially meaningful environment. Participants also feel more confident about their response when the movement path for the 'tour' activity is in its true location (M=4.18), rather than for a false movement path (M=3.14).

As response data are not normally distributed, a Wilcoxon signed-rank test was applied to test whether context has an effect on participants' confidence in their understanding of movement trajectories. The test is based on negative ranks. Overall, participants are significantly more confident with context information (M=3.38) than without (M=2.33), $z=-5.01$, $P<0.05$, $r=-0.755$.

Object recognition

In the second quantitative question, participants had to identify the moving object. The performance of participants is most interesting when aggregating the data according to context correctness, i.e. whether the movement path is presented in its true geographic location (as explained earlier, compare to Figure 12). For the 'piste' behaviour's movement paths, participants perform better with context information than without, but no difference seems to exist between a correct or incorrect location of the movement path. However, we can see a difference when examining the 'tour' behaviour representation of the movement path. In both cases, participants performed better with context information than without, but

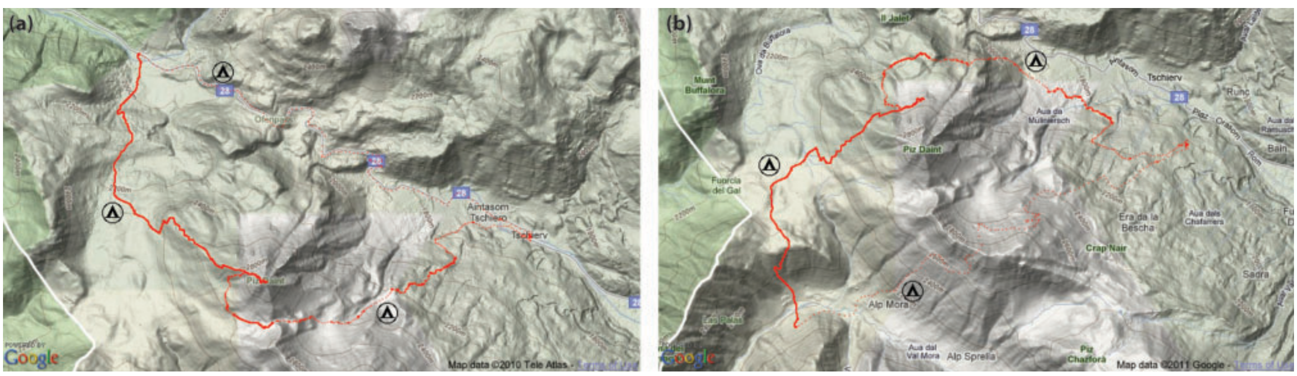

Figure 10. A correctly placed movement path leads to Piz Tarretas (a), while an incorrectly placed movement path (b) does not lead anywhere

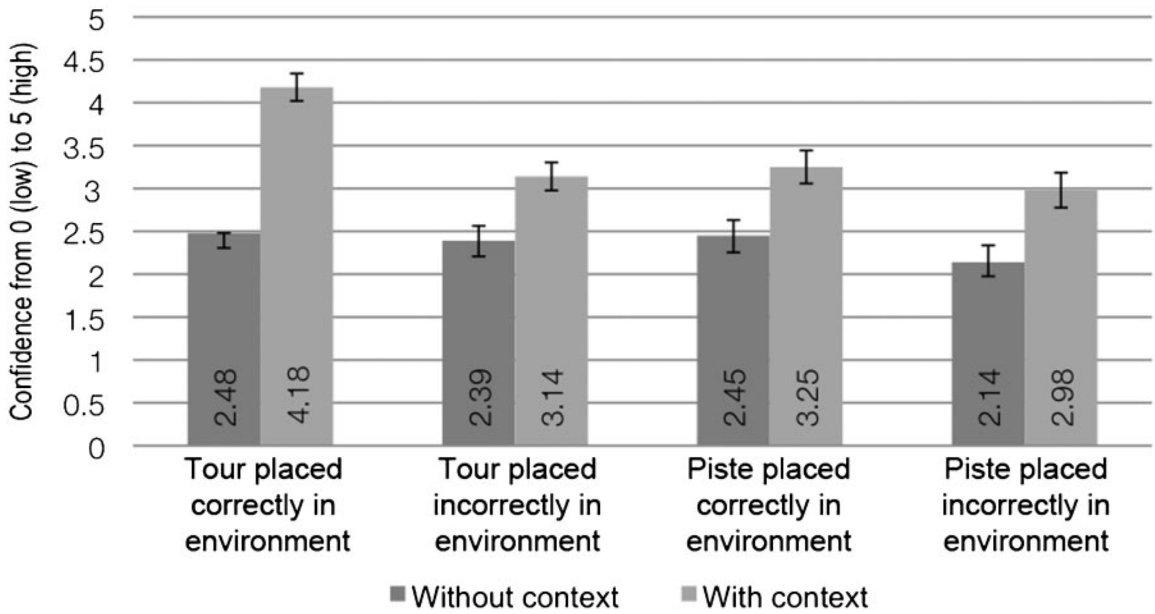

Figure 11. Mean confidence ratings for context correctness

while 81.8% of participants correctly identified the moving object when the path was correctly placed within its context, only 34.1% of the participants identified the object correctly in the incorrectly placed path condition.

A test for a normal distribution revealed that the accuracy values are also not normally distributed. Therefore the Wilcoxon signed-rank test was used. It revealed that 31 participants were more accurate when presented with context information than with no context information. Five participants scored lower when context information is provided and eight participants had tied ranks. The test is based on negative ranks, and z-scores of ± 4.267 are smaller than 0.001. To summarize the accuracy results for both conditions, participants' accuracy was significantly higher with context information (M=57.38%) than without context information (M=31.25%), $z=-4.267$, $P<0.05$, $r=-0.643$. We can conclude that accuracy increases with context information.

We can briefly summarize the quantitative analysis by stating that confidence and accuracy significantly increase with geographic context information.

DISCUSSION

Most participants assumed that humans or animals made the movement path of the 'tour' behaviour, and thus, used

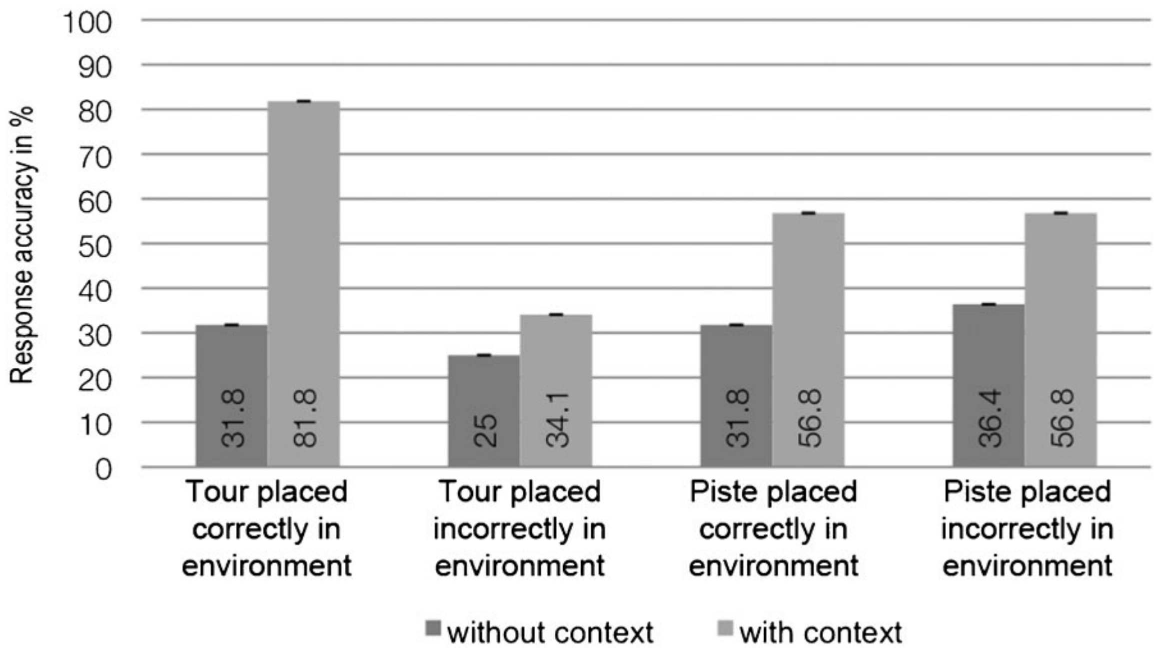

Figure 12. Accuracy of object recognition for correctness of context

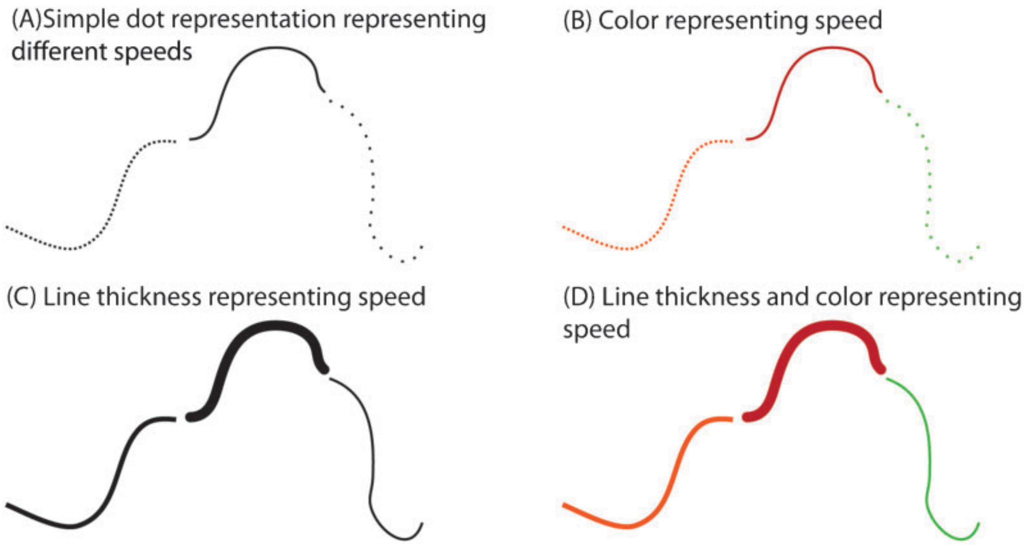

Figure 13. Potential visualisations to depict movement using line thickness and colour as perceptually salient features

a process-oriented concept, which is surprising, as they could have also considered natural phenomena, such as the border of a lake. Participants were not told what kind of representation they were looking at at the beginning of the experiment. Specifically, they were not told that the paths were made with GPS samples. Perhaps the small Google Maps logo displayed in the corner of the display might be responsible for this result.

The 'piste' behaviour was mainly interpreted as an object. It is also interesting to note that most participants used one explanation for the 'tour' behaviour and one explanation for the 'piste' behaviour in the first half of the experiment, and only changed their interpretation with added context information in the second half of the experiment.

Path elements were used independently of context, thus suggesting that these elements are the most prominent features used to identify movement behaviour in these visualisations. The qualitative analysis also reveals that more precise interpretations were given with context information than without context information. Specifically, more participants interpreted the red path as a human movement path when context information was provided, as opposed to a line object or technical object (depending on the behaviour) or the movement path of an animal when no context information was provided.

An interesting effect can be observed when the movement path is not presented in its true location, but is reflected 180°. Participants were more likely to identify the moving objects as animals, rather than humans in these instances. A potential explanation for this effect is that the incorrectly located trajectories cross steep terrain, and participants probably conclude (rightly) that humans cannot traverse this kind of terrain. This corresponds to the response frequencies shown for Question 4, where participants more often referred to the topography in the representation. The lines of the 'piste' behaviour also cross a valley, which is rare in reality. Therefore, participants concluded that the representations are of technical objects, such as water pipes and ski lifts.

Highlighting path elements in movement visualisations

The path elements participants use are mainly the dispersion of points along the line, i.e. individual dots or a thick line, and the shape of the path, i.e. straight and bent lines. These path elements do not necessarily correspond to the geometric features used for the algorithmic analysis of movement patterns, i.e. basic movement parameters such as distance, or direction. As mentioned earlier, neither the change of direction, i.e. turning angles in the movement path, nor the start and end points were considered. This is surprising as change of direction is a common geographic feature used for geographic knowledge discovery with data mining (Laube and Purves, 2011). Additionally, change of direction has shown to be a prominent feature when segmenting a trajectory (Lautenschütz, 2011). It is therefore surprising that this element was not used, despite some direction changes that include a big turning angle in the representation. The dispersion of points along the line, is an indicator of speed. Visualisations of movement could therefore employ this principle and visually highlight line elements in a perceptually salient way, e.g. through colour or size, to contribute to map reader's ability to identify moving objects and their behaviour. Colour coding could be used by employing, for instance, the traffic light metaphor to depict speed, which has been done successfully for real-time traffic maps (Goldsberry, 2008). An example of this is provided in Figure 13.

As mentioned earlier, the use of event-based approaches is common in geovisualisation, as they actively integrate cognitive principles (Yattaw, 1999; Kapler and Wright, 2005; Beard, 2006; Aigner *et al.*, 2008; Beard *et al.*, 2007) and allow users to identify individual components of spatio-temporal behaviour. Combining the de-composition of events and processes with the visual highlighting of path elements could potentially also enhance users' map reading abilities. In Aigner *et al.*'s (2008) approach, for instance, users specify an event according to spatial, temporal or attribute dimensions, in order to be able to detect the event later on. Employing computational algorithms to detect change points and suggest them visually to the user, for example, by applying appropriate salient visual variables, might be a useful enhancement to the tool. The user could then rate suggested events according to their importance with respect to the analysis task at hand. This approach would highlight the important information and could potentially augment people's capabilities for pattern extraction and complex spatio-temporal reasoning.

Two other kinds of visualisations that might be relevant for enhancing visualisations of movement are (1) abstract matrix visualizations (Wood *et al.*, 2010); and (2) trajectory representations (Wood *et al.*, 2011). Both visualisations represent movement with the source–path–goal schema (Lakoff, 1987) and show the direct links and nodes of movement behaviour. Change points, or events, in a movement path similarly reflect the source–path–goal schema as our conceptual understanding of movement processes. Visually representing this understanding using a suitable metaphor could potentially improve the user experience and lead to a better understanding of spatio-temporal processes and behaviour.

Finally, it seems valuable to include (geographic) context into visualisations of movement, because it enables participants to leave the pre-attentive level of seeing a pattern, to actually analyse the movement process and draw conclusions about the object and its behaviour. The result potentially also means that visualisations that show movement data on a map are possibly more effective than visualisations without a map, such as the re-discovered space–time cube (Hägerstrand, 1970) that shows movement in space on a two-dimensional plane. The explicit representation of the location of movement might therefore explain the success of the space–time cube in recent approaches (Kraak, 2003; Kwan *et al.*, 2003; Neutens *et al.*, 2008), at least when showing a small number of trajectories.

Limitations

In our representation of movement, we did not provide a scale for participants, despite the fact that the spatial and temporal scale are important contextual elements, both for the behaviour of an object, the sampling of data, as well as the interpretation of movements. However, a legend with a scale would bias participants to reason about either a large-scale or small-scale space, such as geographic space or a table-top space, which we wanted to avoid. In the interpretations, we have seen that participants identified the representation as movement of ants or bees, as well as a seasonal migration pattern of a lion, thus employing very different scales of reasoning. While the representation is scale-free in the without context condition, scale is induced inexplicitly with the introduction of the topographic map. This is of course a limitation of the study, as participants' interpretations might be scale-dependent and thus not comparable with each other. Experiments in data mining (Laube and Purves, 2011) and reasoning about spatio-temporal phenomena at multiple scales (Klippel and Li, 2009) already exist and reveal that scale has to be considered for the analysis of movement data. A future experiment that assesses the effect of scale on participants' visual analysis and interpretation, and therefore ultimately reasoning with visualisations of movement, is necessary and would be highly beneficial.

Another limitation of this study is the type of context provided here, as the definition of context used in this experiment was fairly narrow and focuses on geographic reference for the moving object. The presentation of context has been done here with a topographic map. However, participants potentially could have interpreted the path differently if it was presented on a street map, as interpretations were also focused on the topography of the movement path. It would be necessary in future work to assess the effect of other types of context, especially the spatial and temporal scale of moving objects, as mentioned above.

Finally, context is not the only factor influencing the understanding of spatio-temporal behavioural with visual representations. Other cognitive factors, such as familiarity and training with handling movement data, have not been evaluated and would require further investigation.

CONCLUSION

The results of this experiment indicate that the dispersion of points along the line and the shape of the representation influence participants' interpretations of moving objects and their behaviour. With this approach, we hope to provide a first stepping-stone to identify the key elements that contribute to a map reader's ability to understand and analyse movement behaviour with visual analytics tools.

By understanding how users conceptualize spatio-temporal data in visualisations, we can integrate these findings into a cognitively inspired approach to their representation, for instance, through the visual highlighting of specific path elements or events. This work therefore opens interdisciplinary research avenues to help solve the larger goal of understanding movement processes on Earth, by working to develop empirically validated design guidelines for movement visualisations.

BIOGRAPHICAL NOTES

Anna-Katharina Lautenschütz has just finished her PhD at the Geographic Information Visualization and Analysis Group at the Department of Geography in Zurich, Switzerland. Her research interests focus on understanding how humans process spatio-temporal information in visualizations.

ACKNOWLEDGEMENTS

This research was funded by the Swiss National Science Fund under grant no. 200020-126657/1. The author appreciates the financial support. I would like to thank Reto Rupf from the ZHAW Wädenswil for the permission to use movement data from the Mafreina Project. I thank Sara Irina Fabrikant, from the Department of Geography in Zurich, for her insightful comments and suggestions that substantially improved this research project. I would also like to thank three anonymous reviewers for their comments and suggestions to improve this paper.

REFERENCES

Aigner, W., Miksch, S., Müller, W., Schumann, H. and Tominski, C. (2008). 'Visual methods for analyzing time-oriented data', **Transactions on Visualization and Computer Graphics**, 14, pp. 47–60.

Beard, K. (2006). 'Modelling change in space and time: an event-based approach', in **Dynamic and Mobile GIS: Investigating Change in Space and Time**, ed. by Drummond, J., Billen, R., Forrest, D. and Joao, E., pp. 55–77, Taylor and Francis, Boca Raton, FL.

Beard, K., Deese, H. and Pettigrew, N. R. (2007). 'A framework fo visualization and exploration of events', **Information Visualization**, 7, pp. 133–151.

Bertin, J. (1983). **Semiology of Graphics: Diagrams, Networks, Maps**, University of Wisconsin Press, Madison, WI.

Buchin, K., Buchin, M., van Kreveld, M. and Luo, J. (2009). 'Finding Long and Similar Parts of Trajectories', in **17th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems**, pp. 296–230, Seattle, WA, Nov 4–6.

Buchin, M., Dodge, S. and Speckmann, B. (2012). 'Context-Aware Similarity of Trajectories', in **6th International Conference on Geographic Information Science (GIScience)**, pp. 43–56, Zurich, Sep 14–17.

Casati, R. and Varzi, A. C. (2008). 'Event concepts', in **Understanding Events**, ed. by Shipley, T. F. and Zacks, J. M., pp. 31–53, Oxford University Press, Oxford.

Chen, C. (2005). 'Top 10 unsolved information visualization problems', **IEEE Computer Graphics and Applications**, 25, pp. 12–16.

DiBiase, D. W., MacEachren, A., Krygier, J. B. and Reeves, C. (1992). 'Animation and the role of map design in scientific visualization', **Cartography and Geographic Information Systems**, 19, pp. 201–214.

Dodge, S., Weibel, R. and Forootan, E. (2009). 'Revealing the physics of movement: Comparing the similarity of movement characteristics of different types of moving objects', **Computers, Environment and Urban Systems**, 33, pp. 419–434.

Dodge, S., Weibel, R. and Lautenschütz, A.-K. (2008). 'Towards a taxonomy of movement patterns', **Information Visualization**, 7, pp. 240–252.

Dykes, J. and Mountain, D. M. (2003). 'Seeking structure in records of spatio-temporal behaviour: visualization issues, efforts and applications', **Computational Statistics & Data Analysis**, 43, pp. 581–603.

Fabrikant, S. I., Rebich-Hespanha, S. and Hegarty, M. (2010). 'Cognitively inspired and perceptually salient graphic displays for efficient spatial inference making', **Annals of the Association of American Geographers**, 100, pp. 1–17.

Fuhrmann, S., Ahonen-Rainio, P., Edsall, R. M., Fabrikant, S. I., Koua, E. L., Tobón, C., Ware, C. and Wilson, S. (2005). 'Making useful and usable geovisualization: design and evaluation issues', in **Exploring Geovisualization**, ed. by Dykes, J., MacEachren, A. and Kraak, M.-J., pp. 553–566, Elsevier, Amsterdam.

Galton, A. (2009). 'Spatial and temporal knowledge representation', **Earth Science Information**, 2, 169–187.

Gianotti, F. and Pedreschi, D. (Eds.). (2008). **Mobility, Data Mining and Privacy – Geographic Knowledge Discovery**, Springer, Berlin/Heidelberg.

Goldsberry, K. (2008). 'GeoVisualization of Automobile Congestion', in **AGILE Workshop on GeoVisualization of Dynamics, Movement and Change**, Girona, May 5, http://geoanalytics.net/GeoVis08/a13.pdf, viewed 31 October 2012.

Gudmundsson, J., Laube, P. and Wolle, T. (2012). 'Computational movement analysis', in **Springer Handbook of Geographic Information**, ed. by Kresse, W. and Danko, D., pp.725–741, Springer, Berlin/Heidelberg.

Gudmundsson, J., van Kreveld, M. and Speckmann, B. (2004). 'Efficient Detection of Motion Patterns in Spatio-Temporal Data Sets', in **12th Annual ACM International Workshop on Geographic Information Systems**, pp. 250–257, Washington DC, Nov 12–13.

Hägerstrand, T. (1970). 'What about people in regional science?', **Papers of Regional Science Association**, 24, pp. 7–21.

Hornsby, K. and Egenhofer, M. J. (2002). 'Modeling moving objects over multiple granularities', **Annals of Mathematics and Artificial Intelligence**, 36, pp. 177–194.

Hornsby Stewart, K. and Cole, S. (2007). 'Modeling moving geospatial objects from an event-based perspective', **Transactions in GIS**, 11, pp. 555–573.

Kapler, T. and Wright, W. (2005). 'GeoTime information visualization', **Information Visualization**, 4, pp. 136–146.

Klippel, A. and Li, R. (2009). 'The endpoint hypothesis: a topological-cognitive assessment of geographic scale movement patterns', **Lecture Notes in Computer Science**, 5756, pp 177–194.

Koh, L. C., Slingsby, A., Dykes, J. and Kam, T. S. (2011). 'Developing and Applying User-Centered Model for the Design and Implementation of Information Visualization Tools', in **15th International Conference Information Visualisation and 3rd International Symposium Information Visualisatization Evaluation**, pp. 90–95, London, Jul 14–15.

Kraak, M.-J. (2003). 'The Space–Time Cube Revisited from a Geovisualization Perspective', in **21st International Cartographic Conference**, pp. 1988–1996, Durban, South Africa, Aug 10–16.

Kwan, M.-P., Janelle, D. G. and Goodchild, M. F. (2003). 'Accessibility in space and time: a theme in spatially integrated social science', **Journal of Geographical Systems**, 5, pp. 1–3.

Lakoff, G. (1987). **Women, Fire, and Dangerous Things: What Categories Reveal about the Mind**. University of Chicago Press, Chicago, IL.

Lakoff, G. and Johnson, M. (1980). **Metaphors We Live By**, The University of Chicago Press, London.

Laube, P., Dennis, T., Forer, P. and Walker, M. (2007). 'Movement beyond the snapshot - Dynamic analysis of geospatial lifelines', **Computers, Environment and Urban Systems**, 31, pp. 481–501.

Laube, P., Imfeld, S. and Weibel, R. (2005). 'Discovering relative motion patterns in groups of moving point objects', **International Journal of Geographical Information Science**, 19, pp. 639–668.

Laube, P. and Purves, R. S. (2011). 'How fast is the cow? Cross-scale analysis of movement data', **Transactions in GIS**, 15, pp. 401–418.

Lautenschütz, A-K. (2011). Assessing the relevance of context for visualizations of movement trajectories. PhD thesis. Department of Geography, University of Zürich. Zürich, Switzerland.

Lloyd, D. and Dykes, J. (2011). 'Human-centered approaches in geovisualization design: Investigating multiple methods through a long-term case study', **IEEE Transactions on Visualization and Computer Graphics**, 17, pp. 2498–2507.

MacEachren, A. and Kraak, M.-J. (2001). 'Research challenges in geovisualization', **Cartography and Geographic Information Science**, 28, pp. 3–12.

Mennis, J. and Guo, D. (2009). 'Spatial data mining and geographic knowledge discovery – an introduction', **Computers, Environment and Urban Systems**, 33, pp. 403–408.

Nathan, R., Getz, W. M., Revilla, E., Holyoak, M., Kadmon, R., Saltz, D. and Smouse, P. E. (2008). 'A movement ecology paradigm for unifying organismal movement research'. **Proceedings of the National Academy of Science USA**, 105, pp. 19060–19065.

Neutens, T., van de Weghe, N., Witlox, F. and de Maeyer, P. (2008). 'A three-dimensional network-based space–time prism', **Journal of Geographical Systems**, 10, pp. 89–107.

Robinson, A., Chen, J., Lengerich, E. J., Meyer, H. G. and MacEachren, A. M. (2005). 'Combining usability techniques to design geovisualization tools for epidemiology', **Cartography and Geographic Information Science**, 32, pp. 243–255.

Schmid, F., Richter, K.-F. and Laube, P. (2009). 'Semantic Trajectory Compression', in **Advances in Spatial and Temporal Databases: 11th International Symposium, SSTD 2009**, pp. 411–416, Aalborg, Jul 8–10.

Schwan, S. and Garsoffky, B. (2008). 'The role of segmentation in perception and understanding of events', in **Understanding Events – From Perception to Action**, ed. by Shipley, T. F. and Zacks, J. M., pp. 391–414, Oxford University Press, Oxford.

Schwartz, R. (2008). 'Events are what we make of them', in **Understanding Events – From Perception to Action**, ed. by Shipley, T. F. and Zacks, J. M., pp. 54–60, Oxford University Press, Oxford.

Shipley, T. F. (2008). 'An invitation to an event', in **Understanding Events – From Perception to Action**, ed. by Shipley, T. F. and Zacks, J. M., pp. 3–30, Oxford University Press, Oxford.

Shipley, T. F. and Maguire, M. J. (2008). 'Geometric information for event segmentation', in **Understanding Events – From Perception to Action**, ed. by Shipley, T. F. and Zacks, J. M., pp. 415–435, Oxford University Press, Oxford.

Slocum, T. A. (2008). **Thematic Cartography and Visualization**, 3rd ed., Prentice Hall, Upper Saddle River, NJ.

Tversky, B., Zacks, J. M. and Martin Hard, B. (2008). 'The structure of experience', **Understanding Events – From Perception to Action**, ed. by Shipley, T. F. and Zacks, J. M., pp. 436–464, Oxford University Press, Oxford.

Wood, J., Dykes, J. and Slingsby, A. (2010). 'Visualization of origins, destinations and flows with OD maps', **The Cartographic Journal**, 47, pp. 117–129.

Wood, J., Slingsby, A. and Dykes, J. (2011). 'Visualizing the dynamics of London's Bicycle Hire Scheme', **Cartographica**, 46, pp. 239–251.

Worboys, M. (2005). 'Event-oriented approaches to geographic phenomena', **International Journal of Geographical Information Science**, 19, pp. 1–28.

Worboys, M. and Hornsby, K. (2004). 'From objects to events: GEM, the geospatial event model', **GIScience**, 3234, pp. 327–343.

Yan, Z., Macedo, J., Parent, C. and Spaccapietra, S. (2008). 'Trajectory ontologies and queries', **Transactions in GIS**, 12, pp. 75–91.

Yattaw, N. J. (1999). 'Conceptualizing space and time: a classification of geographic movement', **Cartography and Geographic Information Science**, 26, pp. 85–98.

Yuan, M. and Stewart Hornsby, K. (2008). **Computatio and Visualization for Understanding Dynamics in Geographic Domains – A Research Agenda**, Taylor & Francis Group, London.

Zacks, J. M. (2004). 'Using movement and intentions to understand simple events', **Cognitive Science**, 28, pp. 979–1008.